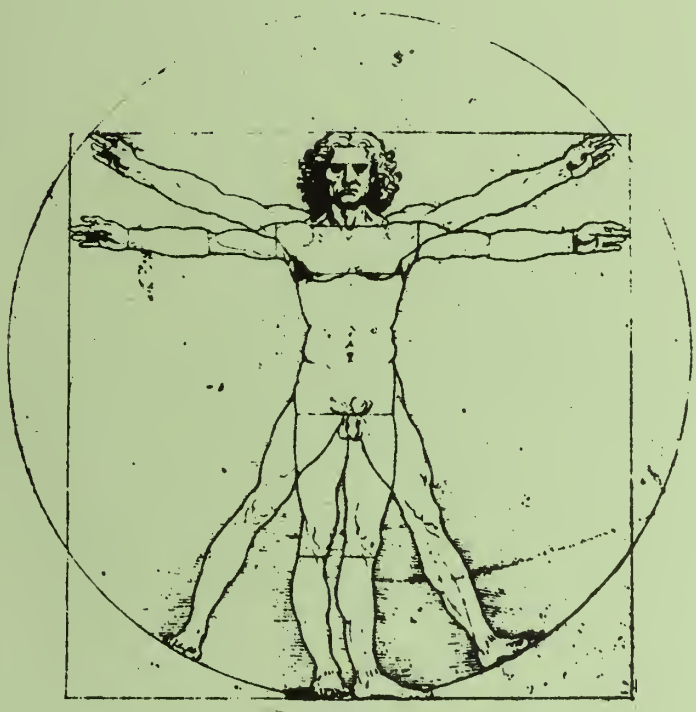
MONTANA AIR POLLUTION STUDY

Air Monitoring Instrumentation
October, 1979



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Front Cover illustration is based on a drawing by Leonardo da Vinci that has come to symbolize human health.

AIR MONITORING INSTRUMENTATION

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MONTANA AIR POLLUTION STUDY

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FOREWORD

This is one of a series of technical reports presenting results from the Montana Air Pollution Study (MAPS), a special air monitoring and health effects project of the Air Quality Bureau, Montana Department of Health and Environmental Sciences. The 1977 Montana Legislature provided the MAPS project with $1.07 million for the 1977-79 biennium to improve understanding of how air pollution affects health in Montana.

The various activities undertaken as part of the MAPS effort have been grouped into five major categories for purposes of project management: Health Effects, Air Quality, Meteorology/Modeling, Emission Inventory, and Statistics and Data Systems. Results from each of these areas are to be presented in a series of reports prepared by the personnel directly involved in the study efforts. There will also be a technical summary report and a report to the public in layman's language.

PREFACE

This report discusses the types of instrumentation used for monitoring of the ambient air during the course of the Montana Air Pollution Study (MAPS). Only air pollution instrumentation is discussed. The first section of the report deals with the cataloging of each type and brand of instrument, with a short description of the instrument and some general comments concerning the instrument's performance during the study period. The second section of the report deals with the particulate monitoring instruments. Since a large number of particulate instruments were in use throughout the project, it became necessary to discuss these instruments in greater detail. It is especially important that the reader be aware of the variations involved among these instruments. A preliminary analysis was conducted on the various instruments, and the results of that analysis are reported in this section.

Harold Robbins, Supervisor of the Air Quality Bureau's Ambient Air Monitoring Section, served as principal author of this report. He was assisted by Alben Myren, James Olsen, Patrick Driscoll and Gary Macon, Ambient Air Monitoring Operators in Missoula, Anaconda, Butte and Billings, respectively.

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EXECUTIVE SUMMARY

Measurement of ambient concentration of various pollutants was a major portion of the Montana Air Pollution Study (MAPS). Under the study design, major air pollution monitoring stations were established in Anaconda, Billings, Butte and Missoula. Smaller sites with only one or two instruments also were established in these cities to augment information from the major stations.

All of the major stations had a variety of samplers, including high volume, dichotomous, membrane, sulfur dioxide and nitrogen dioxide samplers, as well as a meteorological system. Other instruments used in these stations during the study included samplers for ozone, total hydrocarbons, a nephelometer, Beta-counter and others.

The Air Monitoring Advisory Committee selected the pollutants to be monitored, while the Air Quality Bureau selected the brands and styles of instruments. The brands were selected on the basis of: 1) availability within the Bureau; 2) availability from the Environmental Protection Agency; and 3) availability through purchase and capability of meeting the testing procedures specified by the Environmental Protection Agency.

Section II of this report describes the actual brands used and their operating characteristics. Where appropriate, there are comments evaluating how well the instrument functioned throughout the study period. As one might expect, the newer instruments generally operated much better than older ones. More problems were encountered at the Butte Hebgen Park site than at the others, which was probably due to the voltage fluctuation at the site. More significant

problems were encountered with the nitrogen dioxide analyzer than with others. This same trend had been observed by Bureau personnel before the commencement of the MAPS project in July, 1977.

In designing the MAPS project, it was thought that the particulate sampling might be one of the most important aspects of the effort to determine the effects of air pollution on human health. For this reason, at least three particulate samplers were required at all major stations (hi-vol, dichotomous and membrane) and at least one (usually two) particulate samplers at all satellite sites (hi-vol and usually dichotomous). Each of the different particulate samplers was chosen for its ability to measure different ranges of particle size.

The hi-vol is designed to measure all particles suspended in the air. The concentration is determined by weighing a filter before and after the run. The amount of accumulated particulate divided by the amount of air passing through the filter yields the particulate concentration. The hi-vol sampler deals in mass concentration, and therefore tends to be biased to the larger particulate, in that it takes only a few large particles to equal the mass of many small particles. The dichotomous sampler, on the other hand, segregates the particles by size. Three ranges can be determined: 1) particles less than 2.5 microns in diameter (Stoke's diameter); 2) particles between 2.5 and 15 microns; and 3) all particles less than 15 microns. The membrane sampler, by contrast, is designed only to provide a sample for analysis of the chemical constituents. In general, it probably captures particles somewhere between the range of the high-volume and dichotomous samplers.

Besides the above samplers, the MAPS project employed several other particulate measuring instruments. One of these was the nephelometer, which uses the optical effects of particles to measure their relative concentration. The output

from this device is expressed in scattering coefficient and not in mass units. The nephelometer is sensitive almost exclusively to particles between .1 and 1.0 microns. Another device used at the Lions' Park station in Missoula was a Beta counter, which measures TSP and particles less than 3.5 microns on an hourly basis. The principle measurement was by beta-radiation attenuation, which is proportional to the mass of particles on the filter.

A preliminary analysis of the data yielded the type of information that one might expect. Among those relationships are the following:

a. A good correlation exists between the nephelometer and the fine particles measured by the dichotomous sampler.

b. A relatively poor correlation generally exists between the hi-vol and the fine particulates. The relationship improves with the coarse particles (between 2.5 and 15 microns) and is at its best between the hi-vol and the total respirable particles (particles less than 15 microns).

c. No correlation between the fine and coarse particles is necessarily evident.

I. INTRODUCTION

The purpose of this report is to summarize the types of instrumentation used during the Montana Air Pollution Study (MAPS) and discuss the interaction among the various types of particulate sampling instruments. The purpose of this report is to describe some of the techniques used during the project and to discuss problems encountered.

Section II is concerned with the actual air monitoring instrumentation used during the MAPS project. A description of each instrument is given along with some general comments about it. Both the positive and the negative points of each sampler are discussed. The use of any brand names in this report is not intended as an endorsement of these products; it is meant only to be an honest evaluation of the Bureau's experience with a particular brand(s). Age of the instrument and other pertinent information are noted where appropriate.

Section III pertains to an analysis of the different types of MAPS particulate instrumentation. The MAPS project emphasized particulate monitoring, and several different particulate-sampling instruments were used. All major MAPS stations had a high-volume sampler, membrane sampler and dichotomous sampler operating during most of the study. Nephelometers were installed at two sites, one of which also had a Beta-counting particulate sampler. The nephelometers and the Beta-counter were owned by other agencies and included in the MAPS stations under previous arrangements. Section III also addresses the differences between what each instrument measures and attempts to discern any interaction among these instruments.

Section IV briefly summarizes this report.

II. INSTRUMENTATION

This section of the report describes the air monitoring instrumentation used throughout the MAPS project, the reasons for selecting certain sampler types, and reports on the operation of these instruments. It was intended for this section to be in part an aid for those contemplating the use of similar instruments. This report deals only with instrumentation used in the MAPS project. It does not deal with the issue of human intervention in calibration, chart reading or other similar items. The use of brand names in this report does not constitute endorsement by the Air Quality Bureau.

Selection Criteria

The Air Quality Bureau and the Air Monitoring Advisory Committee selected the pollutants to be sampled and the sampling frequency. Once this decision was made, the Bureau selected instruments according to the following criteria:

1. Instruments owned by the Bureau would be used whenever possible.

2. Instruments would be borrowed from the Environmental Protection Agency (EPA) whenever possible.

3. New instruments would be purchased if none were available from either 1 or 2 above. When a new instrument was purchased, it had to meet the EPA "equivalency requirements" meaning it had to pass a test on its response time, lag time, interferences from other pollutants, and so forth. The details of these testing procedures are explained in 40 CFR Part 53 (promulgated 18 February 1975 (40 FR 7044) and amended 17 March 1976 (41 FR 11255) and 1 December 1976 (41 FR 52694)).

If practically possible, the instruments were chosen to meet the equivalency criteria. The use of all equivalent analyzers was nevertheless prohibitively expensive; however, the Bureau feels that the use of non-equivalent analyzers did not significantly affect the data's quality.

Another factor considered in the selection was the Bureau's experience with particular brands. Experience reduced additional training and facilitated instrument repair. A small stock of spare parts was already available for some brands, which reduced the turnaround time for repair and maintenance.

Instrument Description

The following is a list of each instrument used in the project. Comments are based on the Bureau's actual experience and may not necessarily represent the experience of other monitoring groups.

Continuous Gaseous Instruments

Sulfur Dioxide

Beckman 906A. The Air Quality Bureau has been operating this type of instrument for many years, although the instrument has not been submitted for equivalency testing. A Beckman analyzer was used in the Missoula station.

The Beckman 906A operates on the principle of coulometric titration. Approximately 150 cc/minute of air are introduced into a cell containing an almost saturated solution of potassium iodide (and some buffering agents). A constant current is applied between a platinum cathode and anode. If sulfur dioxide is present in the air stream, it will react with the iodine (produced by the anode) and water to produce sulfate ions, hydrogen ions, and iodide ions. This causes an electronic imbalance between the cathode and anode. The excess electric flow is used as the measuring principle. This signal is amplified, conditioned and measured on a recorder. This is a fairly high-maintenance instrument. Since the Bureau has had a great deal of experience with the

Beckman, very little down-time was caused by repairs. Beckman discontinued production of these machines several years ago in favor of a more reliable instrument using a newer detection principle. In general, the Bureau had few problems with the instrument and was able to achieve a high degree of data recovery. One disadvantage to this instrument is its slow response. The instrument was used for only a short time in Butte at the Hebgen Park site and for one full year in Missoula at the Lions' Park Site. The sulfur dioxide concentrations measured in these areas were low. Therefore, one can assume that the response time was not significant in the results of the study.

Phillips 9700. This instrument was obtained on loan from the Environmental Protection Agency (EPA), modified to meet the equivalency criteria, and installed at the Hebgen Park station in Butte. Several of these instruments are also operating at other sites in the Anaconda area as part of another study, and the data may be useful in the MAPS study.

The Phillips 9700 detects sulfur dioxide in the same general manner as the Beckman 906A via coulometric titration. The configuration of the detection cell and the solution (principally bromide) differ significantly from that of the Beckman. The Phillips draws in approximately 300 cc/minute of air to the cell. If sulfur dioxide is present in the air stream, the following reaction occurs in the cell:

$$SO_2 + Br_2 + 2H_2O \longrightarrow H_2SO_4 + 2H^+ + 2Br^-$$

An indicator electrode detects the drop in bromine concentration and causes the generator electrode to produce more bromine. The current flowing through the generator electrode is proportional to the ambient sulfur dioxide concentration.

The instrument was installed at the Butte station in September 1978. It was later discovered that the heating element on the filter inlet assembly was

inoperative, which seemed to cause a poor response in the instrument. Therefore, the data were not recorded until the heating assembly was replaced in January, 1979. No significant flow, zero, or span drift problems were noted. The instrument has not had any further problems since the replacement of the heating assembly. The response time of the instrument appears to be good.

Teco 43. Thermo Electron Corporation (Teco) Model 43 sulfur dioxide analyzers were purchased for the MAPS project and installed at the Anaconda and Billings sites. This brand is an equivalent analyzer and was chosen because it is one of the few sulfur dioxide instruments not requiring chemical solutions or hydrogen gas. The Bureau deemed this a significant advantage over other models.

The detection and measurement of sulfur dioxide is through a pulsed fluorescence technique. Approximately 1.5 liters of air per minute are drawn through the analyzer to the detector area and an instantaneous pulse of ultraviolet (UV) light is introduced into the detection cell. The UV light is limited to a narrow wavelength by means of a narrow-pass filter. Any sulfur dioxide molecules in the detector cell will be excited by this light and jump to a higher energy level. Immediately after the UV pulse is completed, the sulfur dioxide molecules will jump down to ground state and give off a photon of energy. A photomultiplier tube detects these photons and amplifies the signal to a recorder. The photon energy given off is directly proportional to the amount of SO_2 in air. These instruments both performed to factor specifications. However, there seemed to be a break-in period for both instruments. It appears that this would be a normal condition for any instrument that is temperature dependent or contains a source and detector lamp. After this initial break-in period the instruments showed some signs of drift (although within tolerance limits) when the photomultiplier voltage switch was in the low or medium positions.

In order to correct the problem, the photomultiplier voltage was switched to the high position. The instruments have remained relatively constant since that period.

The Teco 43 seems especially sensitive to dirt. As with all instruments, an in-line teflon filter was used to prevent particulates from entering the detector, permeation drier, hydrocarbon cutter, and other sensitive areas of the instrument. Routine maintenance has eliminated possible problems in the areas.

Nitrogen Dioxide

Bendix 8101-B. Bendix analyzers were installed in the Billings and Missoula stations. One of the instruments was owned by the Bureau, and the other was loaned from EPA. Newer versions of this instrument have been designated as "equivalent."

The Bendix analyzer measures nitric oxide (NO), nitrogen dioxide (NO_2) and total oxides of nitrogen (NO_x). It uses the principle of photometric detection of the chemiluminescent reaction between NO and ozone. NO and ozone react readily in ambient air to produce NO_2 and oxygen (O_2). A photon emitted during this reaction is detected by a photomultiplier tube. Various amplification and signal conditioning steps produce the output to the recorder. Since this reaction occurs only between NO and ozone, NO_2 is measured by converting it to NO through a separate channel before introduction to the reaction chamber. Any NO present in the ambient air during this portion of the cycle is not changed by the converter assembly. The concentration (expressed as NO_x) is then subtracted from the original amount of NO to determine the level of NO_2 present in the ambient air. Only the NO_2 channel was recorded during most of the MAPS project.

Both of the Bendix analyzers used in this project were fairly old (approximately five years). More problems would be expected with such analyzers than with newer ones, and the Bureau encountered some difficulties. The drift on the NO_2 channel was relatively low. The drift on the NO and NO_x channels, however, was much greater. Both instruments required considerable maintenance as well as factory rebuilding of the photomultiplier assembly. After the rebuilding, the noise level was significantly reduced in all channels. Drifting in the NO and NO_x channels persisted in one of the instruments despite efforts to correct it. It should be noted that zero and span drift in the NO and NO_x channels do not necessarily cause drifting in the NO_2 channels. Response time for this instrument is excellent, although some transient false negative and positive spikes occurred. The magnitude of these spikes, however, did not cause any significant change in the hourly recorded averages.

Monitor Labs 8440. The Monitor Labs (ML) 8440 analyzer, which is an equivalent analyzer, was installed at the Anaconda station and later at the Lockwood station in Billings. The MAPS project purchased both instruments. An older analyzer was borrowed from the EPA and installed at the Butte station.

This instrument operates in the same general manner as the Bendix 8101, the major difference being that the ML analyzer has two detectors while the Bendix has only one. The Bendix model measures NO and NO_x by cycling between the two channels while the ML has a separate channel and detector for each. The relative advantages of the two methods is subject to debate. Each instrument had its own advantages and disadvantages.

As might be expected, the new instruments performed well while the older ones proved more troublesome. The new instrument in the Lockwood site has not run long enough to establish a track record. The new instrument in Anaconda performed almost flawlessly for the entire period. The instrument was very

stable on all channels, showed a very low noise level, and turned out to be one of the Bureau's most reliable and stable instruments. The older instrument at the Butte station was just the opposite. There was a minimal amount of zero drift in the Butte instrument, but several span drift problems were noted. The drift was particularly evident in the NO_x channel, which would seem to indicate an electronics problem in the analyzer. The span drift deteriorated to the point where the analyzer was removed several times for extensive repairs. Data were unacceptable if the span drift exceeded specifications. There were numerous voltage fluctuations in the Butte station which very likely contributed to the problem. The Bureau plans to install a voltage regulator for this and other voltage sensitive instruments.

Ozone

Bendix 8002. The Bendix 8002 ozone analyzer was operated at the Billings station. The analyzer utilizes the principle of photometric detection of a chemiluminescence reaction. An air stream of about one liter/minute is drawn into a detector. As the stream enters the detector, a small amount of ethylene (25 cc/min) is added. If ozone is present in the ambient air stream, it will react with the ethylene and produce a photon of light, which is detected by the photomultiplier signal conditioning. The instrument is approximately five years old.

There was virtually no zero drift in this instrument. Known levels of ozone were introduced into the instrument with consistent results.

Span drift was also very low. The only mechanical problem noted was with the zero-span-ambient teflon solenoid valve. Once the valve was replaced, the instrument operated with very little trouble.

McMillan 1100. This instrument, lent to the Bureau by EPA, was operated at the Missoula station. The analyzer operates much in the same manner as

the Bendix 8002 instrument, the only difference being the plumbing and photo-multiplier assembly. The McMillan also contains an extra rotameter to monitor the ethylene flow while the Bendix uses a pressure gauge.

The only major problem observed during the operation of this instrument was a fluctuation in the ethylene flow. It was noticed that a small change in ethylene flow can cause a significant change in the calibration. The instrument seemed to be changing flow as the temperature near the cylinder changed. The cylinder was located in the ventilation closet, where it was subjected to changes in outside temperature. This problem was virtually eliminated by installing a needle valve in the ethylene line. Zero and span drift have been well within acceptable limits since the flow problem was solved. The instrument is approximately five years old.

Dasibi 1003 AH. This instrument was purchased by the MAPS project and installed at the Anaconda station. The Dasibi has the advantage over other ozone instruments in that it does not require ethylene gas and is an equivalent analyzer.

The operating principle of this instrument is absorption of ultra violet (UV) light by ozone. A sample of air is drawn through the detection assembly at about 2.0 liters/minute and illuminated with UV light. If ozone is present in the sample stream, it will absorb some of the UV light, and the amount of light reaching the end of the detector will then be reduced. This reduction is detected and recorded. The instrument deals with interferences with other gases by cycling through a "zero" phase about once every twenty seconds. This zero phase selectively scrubs out ozone and allows other gases to pass through the instrument. It is the comparison between the zero phase and the ambient phase that actually quantifies the ozone concentration.

A few erratic readings were noticed when the instrument first arrived. This problem was traced to a loose connection, which probably occurred during shipping. The instrument has operated flawlessly since the problem was corrected. The zero and span values have had virtually no drift since operation began. This instrument has been the most stable and reliable in the entire project.

Total Hydrocarbons

Beckman 109. Beckman total hydrocarbon instruments were operated at the Anaconda and Billings MAPS stations. This analyzer works on a flame ionization principle, which means that a metered amount of air is introduced into a hydrogen-rich flame. If any hydrocarbons are present in the air stream, they will be ionized. A charged plate installed next to the flame absorbs the flow of ionized material. This flow provides a measurement of the amount of hydrocarbons present. This instrument measures all forms of hydrocarbons, although the response of this and all brands of hydrocarbon analyzers is not linear with the size of the carbon molecule. Differences can be noted with not only brands, but also within the same brand.

These instruments are about ten or more years old. Despite their age, they have worked reasonably well. Both machines had a number of electronic problems (most often with the vibrode and batteries), but all were corrected within a few weeks after start up had occurred. Obtaining parts for this instrument proved to be the biggest problem, and most down-time could be attributed to waiting for parts to arrive. The zero and span drift were normally within tolerable limits. A regular maintenance program was necessary to keep the detector clean and batteries fully charged.

MSA 11-2. A Mine Safety Appliance Company (MSA) Model 11-2 hydrocarbon analyzer loaned to the Bureau by EPA was installed in the Missoula station. There are no equivalent methods for this pollutant.

This analyzer works in essentially the same manner as the Beckman 109. However, it has two detectors so it is possible to measure methane and total hydrocarbons simultaneously. The methane channel was not used during the course of the MAPS project.

There were a number of difficulties with the instrument when it first arrived and several months' effort was necessary to make it fully operational. Even after this work was completed, there was difficulty with the methane channel which proved unsolvable. The zero and span stability were quite good. At no time did the instrument drift beyond specifications. Only one major breakdown, which was traced to an electronic component, has occurred since it was brought on line.

Beckman 6800. Obtained by loan from EPA, the Beckman 6800 was located at Hebgen Park in the Butte station. The Beckman 6800 can also measure methane and carbon monoxide. All three channels were used during the MAPS monitoring.

The Beckman 6800 operates on a gas chromatographic principle. The actual detector is a flame ionization detector as described in the Beckman 109 section. Methane is separated from total hydrocarbons by a gas chromatrograph column. Carbon monoxide is measured by first stripping the sample of total hydrocarbons in a chromatographic column and then routing the sample to a catalytic methanator which converts any carbon monoxide to methane. The methane concentration is then read as carbon monoxide. The entire cycle takes approximately five minutes.

Throughout the period the Beckman 6800 operated at Hebgen Park, it proved to be very stable in zero and span drift. No problems were encountered in the operation of the instrument until some electronic malfunctions developed, which

may have been the result of voltage fluctuations common at the Hebgen Park station. The instrument is quite complicated and requires a well-trained operator for reliable operation. In addition to electronic problems, the analyzer also exhibited poor stability in the calibration curve, which can be attributed to water, dirt and other possible contaminants in the hydrogen gas used. The gas is used in the detector and the column as a carrier, and needs to be of high purity.

Carbon Monoxide

Bendix 8501-5BA. The Bendix 8501-5BA carbon monoxide analyzer was operated for several months at the Missoula station. The instrument measures carbon monoxide using a nondispersive single beam of infrared light. The theory of operation is based on carbon monoxide's known absorption ability of infrared (IR) light. An absorption comparison is made between a cell containing ambient air and a cell containing no carbon monoxide. When the same amount of IR light is injected into both cells, the cell containing carbon monoxide will absorb some of the light energy. This change in energy is detected by a charged capacitor and amplified and sent to a recorder.

This instrument has only one major drawback, in that it seems to be vibration sensitive. If the instrument is moved or bumped during operation, erratic readings occur for about forty-five seconds. This required that the Bureau mount the instrument on a vibration-damping table. Except for this minor draw-back, the instrument operated well. Zero and span drift were well within specifications. No repairs of the instrument were necessary. The instrument requires only a small amount of maintenance.

Beckman 6800. The Beckman 6800 was described in the Total Hydrocarbon section above.

Visibility

MRI Nephelometer. The integrating nephelometer constructed by Meteorology Research Inc. (MRI) was installed and operated in the Butte and Missoula stations. The nephelometer is designed to measure continuously the scattering coefficient of light. Light can be scattered by gases, water vapor (60 percent humidity), and suspended particulate. A heating was installed on these nephelometers to reduce the interference of water vapor. Therefore, the instruments were constructed essentially to measure small particulates. The effect on light scattering by particulate of various sizes is not well understood. The nephelometer does not have a definite size cut-off as does the dichotomous sampler. Theoretically, the nephelometer should be most sensitive to particles between approximately .1 micrometer (micron) and 1.0 micron in diameter. However, measurements have shown it to be sensitive also in the 2 to 12 micron range. The instrument is apparently quite insensitive to particles larger than 15 microns.

The MRI nephelometer uses a 44-inch aluminum tube with a photomultiplier at one end and a flash lamp assembly in the middle. Air is drawn continuously through the tube while the flashing assembly sends pulses of light across the diameter. The photomultiplier senses any light that has been scattered by the suspended particles in the atmosphere. The signal from the photomultiplier is amplified and sent to a recorder.

As noted, the Bureau intended that the instrument be used as a measurement of fine particulate concentrations rather than a measure of visibility. The instrument seemed to be subject to more drift than most other monitoring instruments. This variation was not deemed significant because of the large variance that can exist between readings, i.e., variance that is due to readings and not to instrument drift. The instrument at Missoula had relatively few problems,

but there were some initial instability problems with the Butte instrument. Because of these problems, it was taken apart, thoroughly cleaned, and the inside surfaces were painted. From that point on the analyzer performed very well, with only a slight amount of drift.

Manual Instruments

Total Suspended Particulates

General Metals High Volume Sampler. Fourteen high-volume samplers were installed during the MAPS project, two at each of the major sites to allow a daily sampling schedule. These samplers are specified by the reference method for measuring total suspended particulates (TSP).

The high-volume sampler draws approximately 1.15 cubic meters of air per minute through a clean acid washed fiberglass filter which as been conditioned, then weighed in the laboratory. The sampler operates for twenty-four hours and is shut on and off by a timer device. Suspended particulates are drawn into the sampler and trapped on the filter. The filter is again weighed after the run. The difference in mass of the filter divided by the total amount of air drawn through the filter allows determination of the particulate in the ambient air.

The State has many years' experience with these samplers. Their operation is very routine and results in no appreciable problems.

RAC Membrane. A membrane sampler constructed by Research Applicance Company (RAC) was installed at each of the major project sites in Anaconda, Billings, Butte, and Missoula. This is not an equivalent instrument for monitoring particulates.

The operation theory of the membrane sampler is quite similar to that of the high-volume sampler (hi-vol). The reason for using this device along with the hi-vol is to provide for particulate constituent analysis. The filters

used in this instrument were made of a teflon-related material containing virtually no background concentrations of lead, arsenic, copper, or other metals of concern. This allows for a more accurate determination of the composition of particulates in the ambient air. However, the instrument has a much lower air flow rate than the hi-vol, which reduces the size of particles trapped on the filter as a slower airstream has a lower capacity to support heavier particles. The range of particles size collected by this type of sampler is unknown.

The state has years of experience with this device and the operation is generally routine. A new calibration device was used successfully for the instrument, using a mass flowmeter in series with the system. This device facilitated calibration of the sampler.

Small Particulates

Sierra Dichotomous Sampler. Typical for relatively dry climates, several Montana cities experience significant pollution problems with dust, or "particulate matter." The conventional measure of this type of pollution is the total weight or mass, as measured by a hi-vol sampler, and all existing standards and regulatory procedures in the country are based on this type of data. However, the harmful effects of the particulate matter depend very much on the size of the particles. Consequently, it is desirable for many purposes, and almost mandatory for health effects research purposes, to measure the smaller, respirable particles separately.

This is not an easy task, and the development of instruments to do this is very much in a state of flux at the current time. In order to insure having an up-to-date network, the MAPS staff elected to purchase ten units of a type of equipment known as a "virtual impactor" or "dichotomous sampler" from Sierra Corporation in California. These samplers are very clearly the "wave of the future" as opposed to other instruments that are now becoming obsolete. A

negative consequence of this decision was a long delay in delivery, while the manufacturer altered the instruments to comply with fluctuating EPA guidance. With the receipt of the dichotomous samplers, however, the Montana state monitoring network became one of the very few in the country to monitor fine particulate pollution. Coupled with the thorough chemical analysis of the samples, fine particulate sampling will permit a much more informative evaluation of particulate pollution problems in Montana.

The Sierra Model 244 dichotomous analyzer samples and sorts suspended particles into two ranges, those less than 2.5 microns (fine) and those between 2.5 and 15 microns (coarse). The samples are collected on two 37 mm one micron pore size teflon filter. Air is drawn through an aerodynamic device that segregates particles less than 15 microns (mean Stoke's diameter). The air stream is forced through another aerodynamic device which further segregates particles into two size categories: 1) less than 2.5 microns; and 2) between 2.5 and 15 microns. It is important to remember that the separation is aerodynamic and does not necessarily categorize particles stirctly on a size basis. The 2.5 micron cut-off refers to particles of unit density (one gram per cubic centimeter). This means that particles whose density of less than one could possibly end up on the fine filter even though their actual size might be, for example, 3.5 microns. The flow through the instrument is 16.7 liters/minute and held constant by a flow-controller assembly.

Since this is a relatively new sampler type, there was a great deal of learning and testing before actual operation began. A procedure had to be worked out for weighing and transporting filters, and operating the instrument. No major difficulties were encountered with weighing the filters. It was necessary, however, to purchase a microbalance capable of measuring within .01 milligrams. A typical loading of a dichotomous filter was only about 0.70

milligrams. This limits the overall accuracy to only two significant figures. Since the filters could not be marked, they were transported to and from the laboratory in plastic marked petri dishes. In order to ease the problem of confusion between coarse and fine filters, the petri dishes were color-coded with green-coded dishes used for fine filters and white-coded dishes for coarse filters.

Several tests were run to determine whether the petri dishes could be used for mailing the filters. Several fine and coarse filters were carefully transported from the field to the lab and weighed several times. The filters were then returned to the petri dishes and tossed out a second story window onto the lawn. The filters were then reweighed. The fine filter had no change in mass, but the coarse filter lost approximately 50 percent of its original particulate. The same experiment was repeated with another set of filters except that they were thrown down two stories to pavement. Again, the fine filter did not change in mass, but the coarse filter lost approximately 70 percent of the original particulate. As a result, no filters were mailed. All filters were hand delivered from the field to the laboratory, held upright at all times.

One major problem occurred with the sampling device after all of the units were installed. The air flow through the filters dropped significantly during the late fall and winter months at two locations. The cause of this flow change is not clearly understood. It was determined that the flow controller worked well throughout the period. During some preliminary testing several samplers were operated continuously for six days with little or no drop in flow. The Bureau does not believe that the flow drop was caused by either the flow controller or by an excessive mass loading of particles on the filter. The mass loadings during these fall and winter months were no more and usually less than the loading seen during the preliminary tests. After some experimentation it was discovered

that heating the inlet line and the filter area greatly improved the situation. The inlet tube and filter holders were insulated and heated using the heating tape commonly used to keep water pipes from freezing. The heating tape probably heated the air only a few degrees centigrade from ambient, depending on the ambient temperature. The tube felt warm to the touch, but not hot.

The heating tape was equipped with a temperature switch so that it would shut off during warmer days. The sampler seemed to work much better after this modification.

No significant problems were found with the digital timer, flow controller, pump or rotameters. The instrument was calibrated using mass flowmeters in with the filters.

GCA Aerosol Mass Monitor (Beta-counter). The GCA aerosol mass monitor model APM-1 was purchased by the Missoula County Air Pollution Control Agency, installed at the Lion's Park station in Missoula, and operated by state personnel. As yet, the beta-counter has not been designated an equivalent method for the measurement of total suspended particulates. The beta-counter size fractionates and measures the mass concentration of suspended particulates, and the data are generated through a digital printout. No laboratory steps are involved in the process.

Particles are collected on a reinforced glass-fiber filter tape and an upstream venturi-type orifice collects the air at a constant rate, while a cyclone precollector is used on one of the two inlets to collect only particles less than 3.5 microns, while the second inlet collects total suspended particulate. The filter tape is subjected to a Beta-radiation source (carbon 14) before the filter is exposed to particulates. After exposure, the paper is again exposed to the radiation. The difference in the amount of radiation

passing through the filter between the exposed and unexposed filter is proportional to the mass loading. A microprocessor in the instrument prints the concentration of both the fine (less than 3.5 microns) and total suspended particulate readings. The instrument has been installed to give hourly concentrations of both fine and total particulate readings.

This is a relatively new, complex, and expensive monitor, thus leading to a long-break-in and learning process. Some problems with the flow sensors and electronic components had to be solved. Since their solution, however, the instrument has operated quite well. The Bureau found that although the day-to-day operation of the instrument is relatively simple, maintenance usually requires a well qualified electronics technician. Cold weather sometimes produces hoar frost on the screen of the sample intake, possibly producing incorrect readings.

Initial observations and data comparisons reveal that the TSP portion of the instrument follows the hi-vol data well and the fine portion follows the nephelometer data with consistency.

III. PARTICULATE INSTRUMENT COMPARISONS

This section of the report is a comparison among the various types of particulate instruments used during the MAPS project. Since the sampling of particulate was emphasized throughout the project, it is appropriate to discuss the different types of instruments used in particulate monitoring, their operation, and the relationships among the instruments.

Each instrument will be discussed individually. An explanation follows concerning the operation principles of the instrument and the kinds of particles measured by these instruments. The section closes with a discussion of the correlations found to date among these instruments.

There were a total of five particulate monitoring instruments used for the project. The following table briefly summarizes the instruments:

Table I

Name	Parameter Measured	Filter Collection Media	Measurement Principle
High Volume Sampler (hi-vol)	Total Suspended Particulates (TSP)	Fiberglass filters	Gravimetric
Membrane Sampler	Suspended Particulates	Teflon Membrane	Atomic Absorption Spectrophotometry
Dichotomous Sampler	Small Particulates	Teflon Membrane	Gravimetric
Nephelometer	Small particules or visibility	None	Back-scattering of light
Beta Counter	Small particles and TSP	Fiberglass filter roll	Beta-radiation attenuation

The following table is a description of the location of the instruments and their approximate starting date.

Table II

Site Name	Instrument	Approximate Starting Date
Lions' Park, Missoula	Hi-Vol	11/77
Lions' Park, Missoula	Membrane	2/78
Lions' Park, Missoula	Beta Counter	6/78
Lions' Park, Missoula	Dichotomous	9/78
Lions' Park, Missoula	Nephelometer	1/78
McLeod Park, Missoula	Hi-Vol	1/79
McLeod Park, Missoula	Dichtomous	1/79
Courthouse Roof, Missoula	Hi-Vol	***
Courthouse Roof, Missoula	Dichotomous	10/78
Rose Park, Missoula	Hi-Vol	10/78
Lincoln School, Anaconda	Hi-Vol	5/78
Lincoln School, Anaconda	Membrane	7/78
Lincoln School, Anaconda	Dichotomous	8/78
Hi-way Junction, Anaconda	Hi-Vol	***
Hebgen Park, Butte	Dichtomous	8/78
Hebgen Park, Butte	Hi-Vol	6/78
Hebgen Park, Butte	Nephelometer	10/78
Hebgen Park, Butte	Membrane	8/78
Floral Park, Butte	Dichotomous	11/78
Floral Park, Butte	Hi-Vol	11/78
Dr. Canty's Office, Butte	Hi-Vol	6/78
Kiwanis Park, Great Falls	Hi-Vol	10/78
Kiwanis Park, Great Falls	Dichotomous	10/78
Central Park, Billings	Hi-Vol	6/78
Central Park, Billings	Dichotomous	9/78
Central Park, Billings	Membrane	9/78
City Hall, Billings	Hi-Vol	***
Lockwood School, Billings	Hi-Vol	4/79
Lockwood School, Billings	Dichotomous	5/79
Gand Ave. School, Billings	Hi-Vol	***
KGHL, Billings	Hi-Vol	***

*** These sites were in operation several years before the start of the MAPS project.

The varying dates of installation reflects the manufacture delivery schedule and various other problems in instrument installation and operation. Any statistical comparisons made with this data were generally limited to 1978 and the first few months of 1979.

Instrument Description

High-Volume Sampler. The high-volume sampler (hi-vol) has been in widespread use throughout the United States for measuring particulates for many years, and it continues to be a major instrument in the monitoring of air quality levels of particulate for virtually all state and county air pollution agencies. The hi-vol has been designated as the "reference method" for measuring total suspended particulates (TSP). The term "reference method" means that the Environmental Protection Agency (EPA) has designated this method to be the standard method for measuring TSP. Other methods are acceptable if they can be shown to agree with the reference method, according to guidelines in 40 Code of Federal Regulations Part 53.

Air is drawn into the sampler (a covered housing) through a filter by means of a vacuum blower. Typically the air flow is 1.13 cubic meters per minute. The sampler is operated for a period of twenty-four hours for each sample run. A clean unexposed filter is weighed in the laboratory before the run and once again after the run is completed. The difference is mass divided by the total cubic meters of air passing through the filter yields the total suspended particulate value.

Glass-fiber filters were used to collect the particulate matter. The Environmental Protection Agency supplied the filters, and all state and county air pollution agencies used them for particulate monitoring. The filters are designed to capture at least 99 percent of all 0.3 micron particles (using the DOP test as described in the Federal Register).

The sampler captures particles between .01 microns and 80 microns. Unfortunately, there is no clear-cut pattern of particle size cut-off for the hi-vol sampler as is the case for the dichotomous sampler. The instrument is not designed to record a range of particle sizes but rather to record total

mass of all particulates suspended in the atmosphere. The instrument almost certainly accentuates the larger particles, since only a few large particles will contain more mass than a large amount of smaller particles.

Dichotomous Sampler. A Sierra Model 244 dichotomous sampler, very new to the air monitoring scene, was used for the MAPS project. These samplers were among the first constructed of commercial 2.5 micron fine particle size instruments. There are currently no ambient standards for small particles. The Environmental Protection Agency, however, is currently researching the matter and considering proposing a standard in the next few years.

Air is drawn into the sampler at a rate of approximately 16.7 liters/ minute.. The air is forced around a sharp turn at the sampling head causing particles larger than 15 microns (aerodynamic size) not to enter the sampler. The air is drawn down a tube, accelerated, and then forced through a sharp ninety degree turn. Particles larger than 2.5 microns will not be able to make this accelerated turn and will drop onto a filter below the turn. Particles making the turn will impact upon another filter, which traps particles less than 2.5 microns. A small amount of air (1.67 liters/min) is drawn through the coarse filter (the filter containing particles larger than 2.5 microns) to insure that the particles are impacted onto the filter and will not reenter the air stream to settle on the fine filter (less than 2.5 microns). The filters are weighed before and after the run to determine the mass loading. The mass loading divided by the volume of air passing through the sampler yields the particulate concentration (micrograms/cubic meter).

It is important to remember that the cut-off sizes (2.5 and 15 microns) are aerodynamic cut-off points. That is to say that the separation of the particle sizes is accomplished through aerodynamics. The cut-off size applies only to particles of unit density (1 gram/cc) and spherical shape. If a

2.5 micron particle as described above were to enter the sampler, it would have a 50-50 chance of falling on the fine filter. If a 2.0 micron particle were to enter the sampler, it would have approximately a 70 percent chance of falling on the correct filter. Similarly, a particle of 20 microns will have a 35 percent chance of entering the sampler. The following two figures show the collection efficiency of the sampler as described in the Sierra Instruction Manual. Note that the collection efficiency for the fine particle device is 3.5 microns. The samplers used for this study, however, had a cut-off of 2.5 microns.

It appears that from the viewpoint of air pollution health effects, the above may be a valid way of differentiating particle sizes. The nose and lungs also separate particles by means of aerodynamics. As air is drawn through the nose or mouth, the air is forced around sharp turns. Large particles presumably are unable to make this turn and drop out or are scrubbed out by moisture of nose hairs. It is generally believed that most particles likely to enter the lung are 2.5 microns or less.

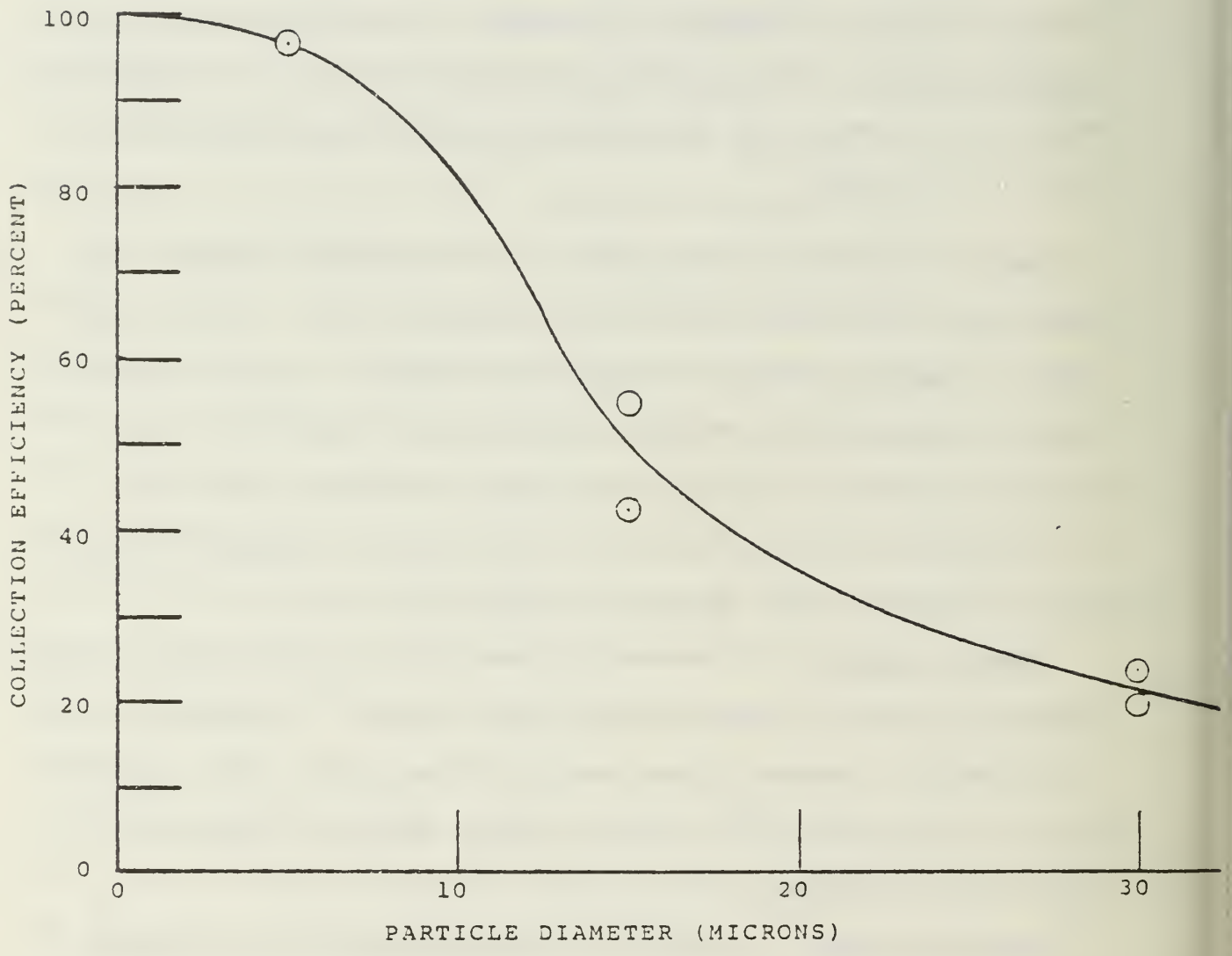
Membrane Sampler. The membrane sampler constructed by Research Appliance Company was used for all MAPS air monitoring stations. The sampler has been in existence for a number of years and as such the Bureau is very familiar with its operation and calibration procedures. There are no ambient air standards for this method.

The method has much in common with the dichotomous and hi-vol methods already described. Air is drawn through a filter by means of a large carbon-vaned vacuum pump. The filter used for this sampler is composed of a teflon-related material. The pore size of the filter used during the project is 3 microns. The main purpose for using a membrane sampler instead of a hi-vol or other particulate samplers is to allow elemental analysis of the particulate

Figure 1

Collection Efficiency of Aerosol Inlet

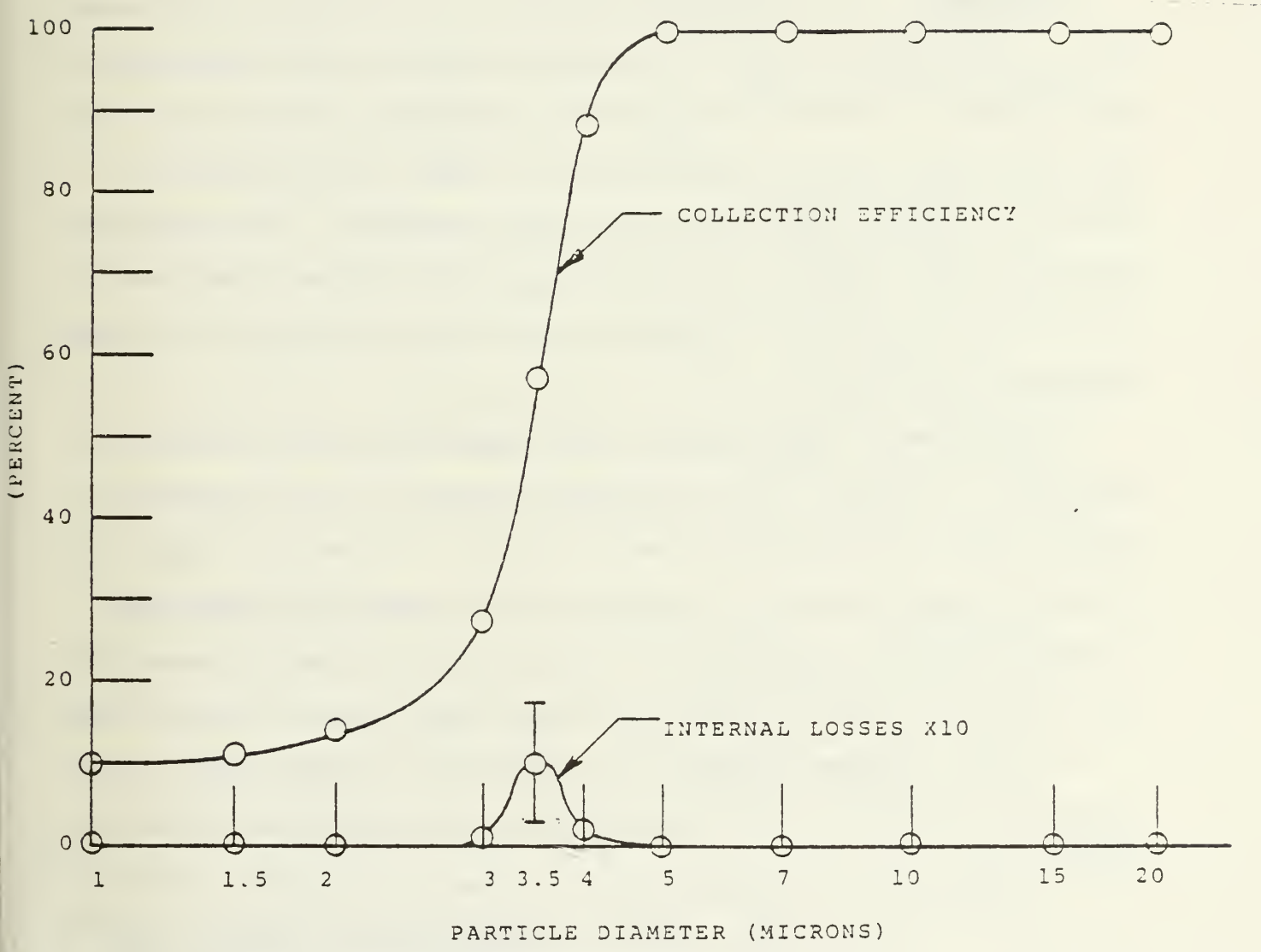
Sampling Head



Source: Sierra Instruments, Inc. Instruction Manual for Series 244 Dichotomou Sampler and Accessories

Figure 2

Collection Efficiency and Internal Losses
of
Fine Particulate Seperation Device



NOTE: The collection efficiency at 50% for the fine particulate is 2.5 microns and not 3.5 microns as shown.

Source: Sierra Instruments, Inc. Instruction Manual for Series 244 Dichotomous Sampler and Accessories.

without being concerned about any background material. The air flow rate through the membrane filter is approximately 0.12 m^3/min. compared to 1.13 m^3/min. for the hi-vol. As with the hi-vol sampler, there is no clear cut-off particle size range.

Nephelometer. The nephelometer has been used by meteorologists for many years as a means of determining the turbidity or amount of light scattering in the atmosphere. The Model 1550B integrating nephelometer constructed by Meteorology Research Inc. was used at two of the MAPS air monitoring sites. There are no ambient standards relating to the nephelometer. The Environmental Protection Agency, however, is considering use of this instrument along with several others for analysis of visibility as related to Prevention of Significant Deterioration regulations.

The nephelometer takes advantage of the scattering of light by particles. For example, if a beam of light were directed through air, some of the light would be reflected by particles present in that air. The amount of light scattered by these particles is at least partially proportional to the number of particles and hence proportional to the particle concentration. The nephelometer measures the amount of light scattered at ninety degrees to the light beam.

The actual parameter measured by the nephelometer is known as the scattering coefficient or extinction coefficient. The scattering coefficient is defined as:

$$\frac{\Delta I}{I} = e^{-b X}$$

where: b = scattering coefficient
I = change in light intensity from traversing a known path length
I = light intensity of source
x = path length

The scattering coefficient depends on characteristics of two things, particles and gases. Certain gases have the ability either to absorb or to scatter light. The effect of this phenomenon can be limited by zeroing

the instrument with the same type of air used for particulate sampling. Humidity can also greatly affect the response of the nephelometer. Water droplets and particles growing due to absorption of water can be detected. In order to remove this effect a heater was placed in-line with the nephelometer to reduce overall relative humidity and therefore to reduce water droplets and particles that would absorb light. (Note: the Missoula nephelometer did not have a heater until April 1, 1978).

The scattering coefficient is also sensitive to the size of particles in the air. This is generally a result of the wavelength of light used by the nephelometer. The MRI nephelometer is limited to light in the visible range for instrument operation. Particles between .1 and 1 micron are especially sensitive to light scattering since visible light is approximately .5 microns. As an example, it would require approximately 20 ug/m^3 of five micron particles to produce the same response from only 1 ug/m^3 of one micron particles.

Beta-Counter Mass Monitor. The beta-counter monitor is a relatively new instrument to the air monitoring field. A GCA Corporation APM-6000 was used in Missoula during the MAPS study. This instrument was purchased by the Missoula County Air Pollution Agency and installed at the Lions' Park site. The instrument measures both fine particles and total suspended particulate. This method of measuring TSP has not yet been designated as a reference or equivalent method by the Environmental Protection Agency.

The beta-counter is designed to measure particulates of two size ranges: 1) particles less than 3.5 microns; and 2) total suspended particulates (same size range as the hi-vol). Air is drawn through a round head at approximately 60 cubic feet per minute (same rate as hi-vol). A portion of this air is isokineticly removed and routed to a reinforced glass-fiber filter tape. The

concentration of particulate is determined through beta-radiation attenuation. The fine particle fraction is analyzed in the same way except that the air stream is forced through a cylcone which allows only particles smaller than 3.5 microns to impact on the filter paper.

The filter paper is subjected to a beta-radiation source (carbon-14) before the filter is exposed to particulates. After the exposure, the paper is again subjected to the radiation. The difference in the amount of radiation passing through the filter between the exposed and unexposed filter is proportional to the mass loading. A microprocessor in the instrument prints the concentration of both the fine and TSP readings. The instrument has been installed to determine hourly concentrations of both particulate readings.

It is important to note that the separation of particle sizes is accomplished in essentially the same fashion as in the dichotomous sampler. The cut-off point refers to aerodynamic cut-point as described in the dichotomous portion of this report.

Instrument Relationships

Comparison of Membrane and Other Particulate Monitors. The correlation between the particulate measured by the membrane sampler and other particulate monitors is probably the weakest. The Bureau is not determining the mass of particulate collected on the membrane sampler, although it is using the membrane sampler for elemental analysis of particulates captured by the sampler. It is possible that certain constituents of the particulate found on the hi-vol sampler may correlate with that of the membrane sampler. A correlation may also exist between particulate monitors and the membrane sampler if the source of the particulate remains relatively unchanged. For example, if one industry were dominating the particulate of any given station, a correlation

would probably develop among one or several elements measured by the membrane sampler and another particulate monitor.

It is important to remember that the flow rate through the membrane sampler is only about one-tenth of the flow rate through the hi-vol sampler. This suggests that the particle sizes captured by the membrane sampler are probably smaller than those captured by the hi-vol. A review of the literature, however, failed to reveal any discussion on the particle size differences. No calculations were performed to determine correlations among these parameters.

Comparison of Hi-Vol and Dichotomous Samplers. The dichotomous sampler measures a portion of the particles detected by the hi-vol sampler. Therefore, an interaction between the two samplers would be a function of the particulate distribution. The particle distribution is a function of the emission source, seasonal, diurnal, and weekly variations. One might find some correlation between the hi-vol and dichotomous sampler within any one of these variations. The correlation may also be a function of which dichotomous measurement is considered. The weakest correlation would probably be between the fine particles (less than 2.5 microns) and TSP. This is expected since the hi-vol is biased to the larger particles. The correlation between coarse particles (2.5 to 15 microns) TSP will improve while the strongest correlation should be between respirable particulates (less than 15 microns) and TSP.

Some preliminary statistical analyses were performed with the hi-vol and the dichotomous sampler at the major MAPS sites. Only two stations out of eight did not show a good correlation coefficient, i.e., at least .80, between total respirable particulates and TSP. The two stations, Central Park in Billings and Kiwanis Park in Great Falls, had correlation coefficients of .70 and .75, respectively. The slope in all cases ranged from .578 to .771. It would seem that this is a narrow range of slopes for areas of Montana containing quite different compositions of particulate sources.

A comparison between the coarse particulates and TSP did not show such a good correlation. Only four of the eight stations showed a correlation coefficient above .80. The slope of these lines ranged from .472 to .556, still a narrow range. The lowest correlation coefficient was .57.

The fine particulates and TSP comparison showed that only the Hebgen Park station in Butte and the Lions' Park station in Missoula showed a strong linear correlation coefficient. The slope for these two sites was .112 and .214, respectively. It is interesting to note that at these two stations only about 25 percent of the readings had a fine particulate concentration greater than the coarse. This observation is opposite to the observation at the other six sites, which may suggest something about the particle composition at these two sites.

Comparison of Hi-Vol Samplers and Nephelometer. The correlation between the hi-vol and nephelometer is not likely to be strong. Since the nephelometer is sensitive to small particles, particularly those between .1 and 1 microns, it should not correlate well with the hi-vol. The nephelometer has one major advantage over the hi-vol in that it measures hourly concentrations while the hi-vol measures only twenty-four hour averages. Hourly readings allow the consideration of diurnal patterns. Since the hi-vol accentuates larger particles, any existing correlations would probably be in the same general time frames, such as seasonal or weekly patterns. If the ratio between very fine particles and total particles remains constant during these periods, some correlations could be observed.

The correlation coefficient between the nephelometer and TSP turned out to be a little better than might have been expected. Only two nephelometers were operated in the network. The correlation coefficient between the two parameters at Hebgen Park was .59 while the correlation coefficient at Lions' Park was .44.

Comparison of Hi-Vol and Beta-Counter Samplers. The correlation between particulate measured by the hi-vol and the fine fraction of the beta-counter (less than 3.5 microns) would be the same as described in the dichotomous section. Relationships may exist with temporal variations, but are not likely to be strong.

One would expect a good correlation between the beta-counter total fraction and the hi-vol. This sampler was partially designed to measure and possibly to replace the hi-vol sampler. Air is drawn into the sampler at approximately the same rate as in the hi-vol and presumably the same size particles are observed. The design of the sampling head is different than the hi-vol which may add a bias into the comparison. The head of the beta-counter is better designed so that there is a minimal bias in the size of particles sampled as a result of wind speed and direction variation. The hi-vol, however, has a bias based on orientation to the wind. It has been observed that if the wind is blowing at a 45^{o} angle to the instrument, it will yield a higher value than if the wind were at a 90^{o} angle. The cause of this phenomenon is not understood.

The relationship between the total beta-counter fraction and TSP should be good. The only variations that may occur would probably be from the sampling head. The magnitude of the variation is not known.

As expected, an excellent correlation coefficient was observed at Lions' Park between TSP and the Beta-counter TSP. An error in several months' Beta-counter data was observed, which invalidates the correlation coefficient and slope calculation. The error, however, caused the correlation coefficient to be smaller then it should have been. The correlation coefficient turned out to be .94 with the incorrect data. Time did not permit correcting these data for publication.

The same problem was observed with the fine particles measured with the beta-sampler. A correlation coefficient of .48 was observed. It is not known, however, what changes will occur when the data are corrected.

Comparison of Nepholometer and Dichotomous Sampler. Both the nephelometer and the dichotomous sampler measure small particles. As a general rule, one would expect a good correlation between the two. The nephelometer is especially sensitive to particles smaller than 1 micron. The fine fraction of the dichotomous is most sensitive to particles less than 2.5 microns. If the ratio of particles from 1 to 2.5 microns remains consistent or if the amount of 1 to 2.5 micron particles is small, a good relationship should be evident.

A correlation between the coarse and respirable particles of the dichotomous sampler would be difficult to predict. In general, a fair correlation should develop. Even though the nephelometer is most sensitive to particles less than 1 micron, it is quite capable of measuring particles in the 5 to 10 micron range. If a small number of these particles is present relative to the amount of fine particles, an association between the two instruments will be evident. The correlation between the coarse and respirable particles to the nephelometer would be most affected by particle distribution.

The data showed what one would normally expect between the nephelometer and the fine particulate dichotomous sampler. The two sites containing both instruments had a correlation coefficient of .98 and .87 for twenty-four hour samples. However, the correlation for coarse particles was quite weak, with correlation coefficients of .35 and .23. As expected, the correlation slightly improved by using the total respirable particulates, of which the fine particles are a portion of the total, with coefficients of .63 and .53.

Comparison between Nephelometer and Beta-Counter. What has already been discussed about the hi-vol and nephelometer will apply to the beta-counter total particulate fraction. As already discussed, a good correlation would be expected between the hi-vol and beta-counter total particulate, since they are designed to measure the same thing.

The beta-counter fine fraction should exhibit the same data association as the fine particulates in the dichotomous sampler. Only a slight bias may occur because of the different cut-off sizes. As a rule, the number of particles in the 2 to 4 micron range is quite small in most urban and non-urban atmospheres.

The same problem mentioned earlier about the Beta-counter data applies to this comparison. A .27 correlation coefficient was observed with the TSP Beta values and a .68 coefficient was observed for the fine particulates. It is not clear what effect correcting the data will have on these coefficients.

Comparison of the Beta-counter and Dichotomous Samplers. The correlation between the beta-counter total particulate and the dichotomous is expected to be the same as the correlation between the hi-vol and dichotomous sampler. A correlation may develop with fine particles if the temporal variations are limited and if the source contributions do not vary in the same time patterns. The correlation should improve with the coarse and respirable particulates since they become a larger percentage of the total suspended particulate.

The correlation between the dichotomous fine and the Bega-counter fine fraction ought to be very good. Both are measuring fine particles of relatively the same size. It is generally believed that the number of particles in the 2 to 4 micron range is quite small in most areas. This would suggest that the cut-off point does not greatly change the particle concentration.

Correlation coefficients are not reported here since some of the Beta-counter data are in error. Time did not permit correcting the data before publication.

IV. SUMMARY

This report discusses air monitoring instrumentation involved in the MAPS project. A description of the types of instrumentation used and a discussion of the data associations between various particulate instruments was included. It is hoped that this report helped to convey some of the techniques used during the project as well as some of the problems involved in monitoring and how they were handled. Since particulates played such an important role in this study, a special section was devoted to particulate sampling instrument operation and the relationships among various types of instruments.

The selection of air monitoring parameters was made by the MAPS Air Monitoring Advisory Committee, while the selection of brands was made by Air Quality Bureau personnel. Instruments were used or purchased under the following ordered criteria: 1) instruments already existing in the Bureau were used first; 2) instruments were borrowed from the Environmental Protection Agency whenever possible; and 3) new instruments were purchased if not available from 1 or 2 above. New instruments had to meet requirements established by the Environmental Protection Agency.

Sulfur dioxide instruments were generally used with success at the MAPS sites. Only one station (Butte, Hebgen Park) had low data collection because of the slowness in parts delivery. The Bureau generally has had a great deal of experience with these types of instruments, which helped keep instrument malfunctions to a minimum.

The instrument that was probably the most difficult to deal with was the nitrogen dioxide analyzer. More malfunctions occurred with this instrument

than any other. The reason can generally be attributed to the complexity of the instrument. Although the Bureau has had some experience with this instrument, it was unable to maintain a good record of data collection. The newer instruments, however, met with good success.

Ozone instruments generally had the best record of performance for instruments yielding hourly readings. As one might expect, most ozone instruments are relatively less complex than sulfur dioxide or nitrogen dioxide analyzers. The calibration procedure for this instrument, however, is quite complex. It can be generally said that the ozone data are probably quite accurate and complete.

The total hydrocarbon analyzer varies greatly from model to model. One particular model worked very well while the other (Butte, Hebgen Park) had some severe electronic malfunctions. It is believed that the power fluctuation at the station was responsible for this problem. If resources allow, an attempt will be made to reduce the power problems at this station in order to increase data quantity.

The carbon monoxide analyzer worked extremely well at Lions' Park and Hebgen Park. Data from these instruments is expected to be among the most accurate under the study.

The nephelometer (visibility and small particulates) generally ran without incidence. Aside from some normal preventive maintenance and some minor repair, both instruments operated well throughout the period. The instrument was calibrated with freon gas as a source of aerosol. This is the standard calibration technique.

The total suspended particulate instruments (hi-vol and membrane sampler) all operated adequately throughout the period. The instruments are simple and easy to operate. The Bureau has had many years' experience with both instruments.

The dichotomous sampler presented a number of problems. Since it was a new type of instrument at the time of the study, the Bureau was required to conduct a great deal of background and experimental work. After several weeks of trials, a standard method for coding, shipping and weighing filters was developed. Some problems of sampler plugging occurred in the winter but were alleviated by heating the inlet air to the filter.

Five particulate measuring devices were used at various stations throughout the project. The devices and their locations are as follow:

Name	Parameter Measured	Locations
Hi-Vol	Total Suspended Particulates	All
Membrane	Suspended Particulates (11 elements)	All major sites
Dichotomous	Small Particles	All major and most satellite sites
Nephelometer	Small particles or visibility	Butte - Hebgen Park; Missoula - Lions' Park
Beta Counter	Total suspended particulates and small particulates	Missoula - Lions' Park

A comparison between the membrane sampler and the other monitors is difficult to make. The membrane sampler has a lower air flow than the hi-vol, and a higher air flow than the dichotomous. Therefore, the size of sampled particulates is assumed to be somewhere between what is sampled by the other two samplers. The membrane was not used to measure total particulate loading, but to measure the amount of specific constituents on the filter. No statistical comparisons were made with this instrument.

Somewhat surprisingly, the hi-vol correlated better with the dichotomous than might have been expected. A good correlation was observed between TSP and total respirable particles in six of eight stations. Four stations had a good correlation between the coarse particles (particles between 2.5 and 15 microns

in diameter) and the hi-vol's total suspended particulates. The correlation was weakest when comparing the hi-vol and the fine particles. Only the Missoula-Lions' Park and Butte-Hebgen Park sites had a correlation coefficient above .80.

A comparison between the nephelometer and the hi-vol yielded what might be expected. The correlation coefficient at the two sites containing a nephelometer was very weak to the hi-vol (.44 and .59).

A good correlation was found between the Lions' Park hi-vol and the Beta-counter TSP reading. After the analysis was performed, however, an error was found in two months of data. It is believed that correcting this data will improve the relationship. The correlation coefficient with the incorrect beta-counter data was .94.

A good correlation between the nephelometer and the fine particulate of the dichotomous sampler was observed. The correlation between the coarse particulate and the nephelometer was quite weak (.35 and .23 coefficients).

Comparisons were made using mostly 1978 data and to a small extent data from early 1979. A more useful comparison can and will be made after the data collection is complete in early 1980.

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